"3-DIMENSIONAL RETARDING WALLS AND FLOW IN THEIR VICINITY"

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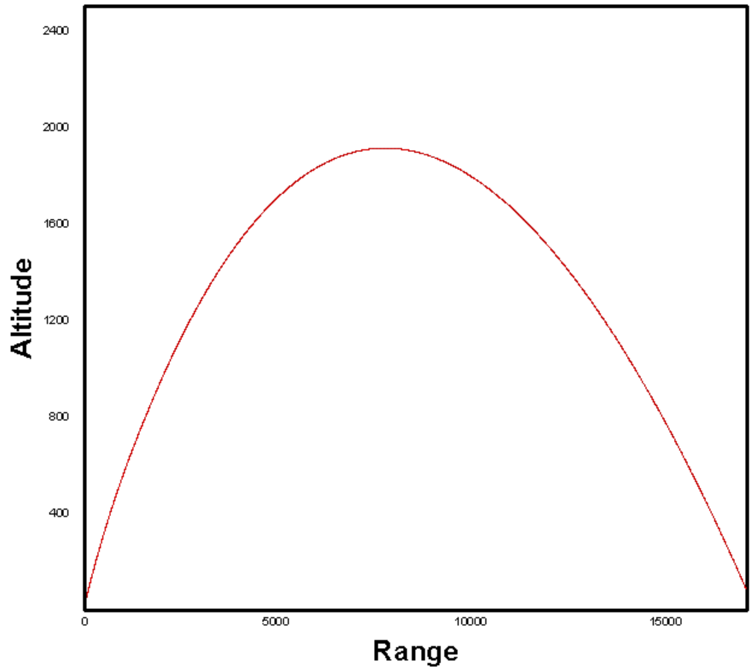
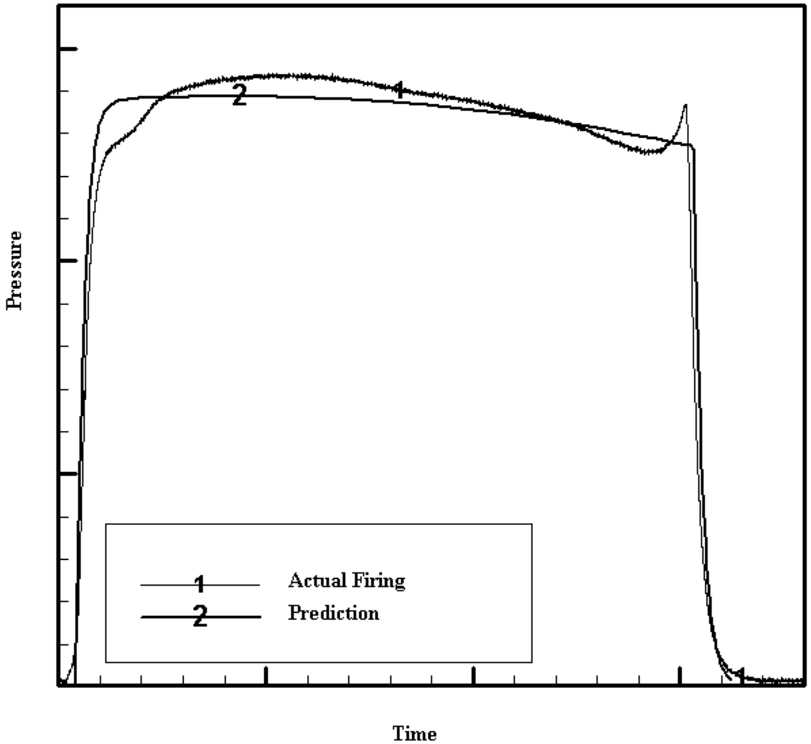
Contents

Introduction

Solid Rocket Motor (SRM) mission design requires the performance prediction of the motor until burnout.

The experimentation cost is very high due to manufacturing of SRM and due to the instrumentations required. Therefore before any product design is completed for experimentation, it should be investigated in details by internal aerodynamic solutions for minimum design correction.

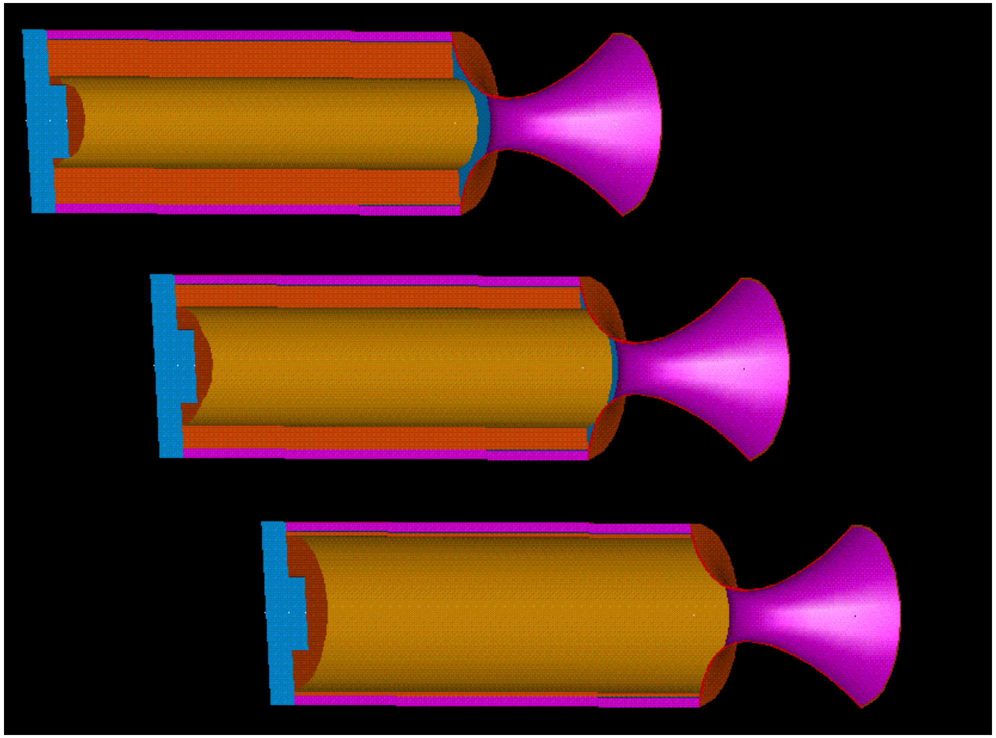




Introduction

The internal aerodynamic solution for SRM is complicated with nearly every aspect of Computational Fluid Dynamics' (CFD) topics. The full SRM solution requires:

1. High Speed Turbulence Modelling
2. Combustion
3. Two-phase Flows
4. Acoustics



In addition to complexity of physics, the control volume in which the flow solutions will be carried out is not constant.

As the combustion continues the grain surface moves towards the propellant, thus increasing the flow volume. The CFD solutions require unsteady flow solutions.

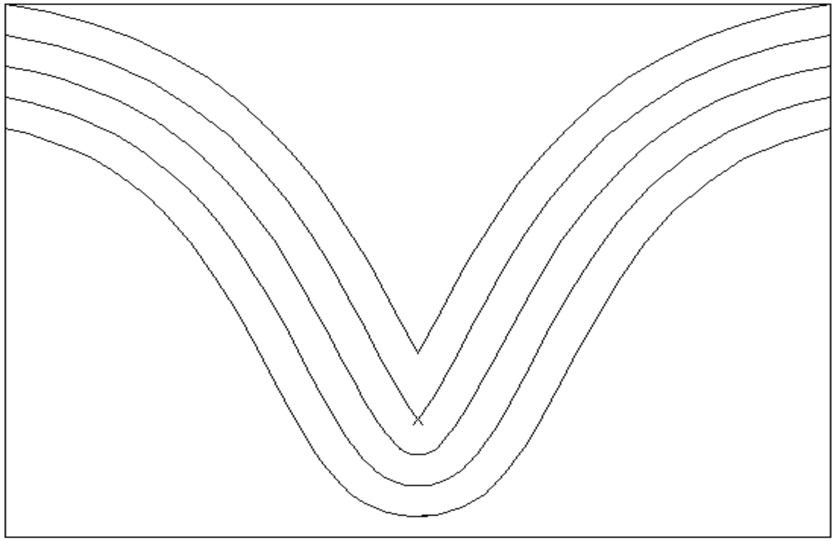
Introduction

In this project the regression of combusting surface of solid propellant in rocket motors is investigated by using a fully 3-dimensional method which is called the **“Fast Marching Method (FMM)”.**

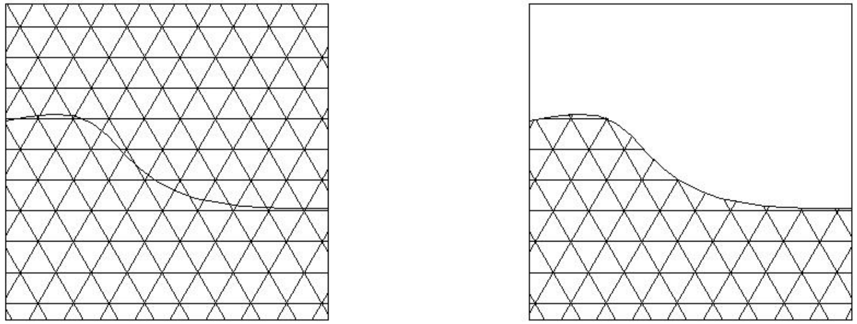
The FMM is capable of following the surface regression under local rate variations by itself. However the aim is to use a varying burn rate under the effects of pressure and velocity. Different flow solvers are coupled with the FMM.

At each time step the FMM will generate mesh files for the solver and obtain fluid properties and therefore the burn rate.

Surface Regression



The fluid-propellant interface moves in the normal direction to the surface. The speed of the motion is dependent upon the rate of burn of the propellant which is dependent upon the properties of the internal flow.



(a) Interface Capturing

(b) Interface Tracking

The interface can be located either by tracking the interface (Lagrangian) or by capturing (Eulerian) on stationary mesh. The FMM method is of Eulerian type.

Surface Regression

Fast Marching Methods (FMM) are numerical algorithms for solving the nonlinear Eikonal Equation on a Cartesian mesh.

$$\|\nabla u(x)\| = F(x) \quad \text{in } \Omega, \quad F(x) > 0$$

$$u = g(x) \quad \text{on } \Gamma$$

General Eikonal Equation

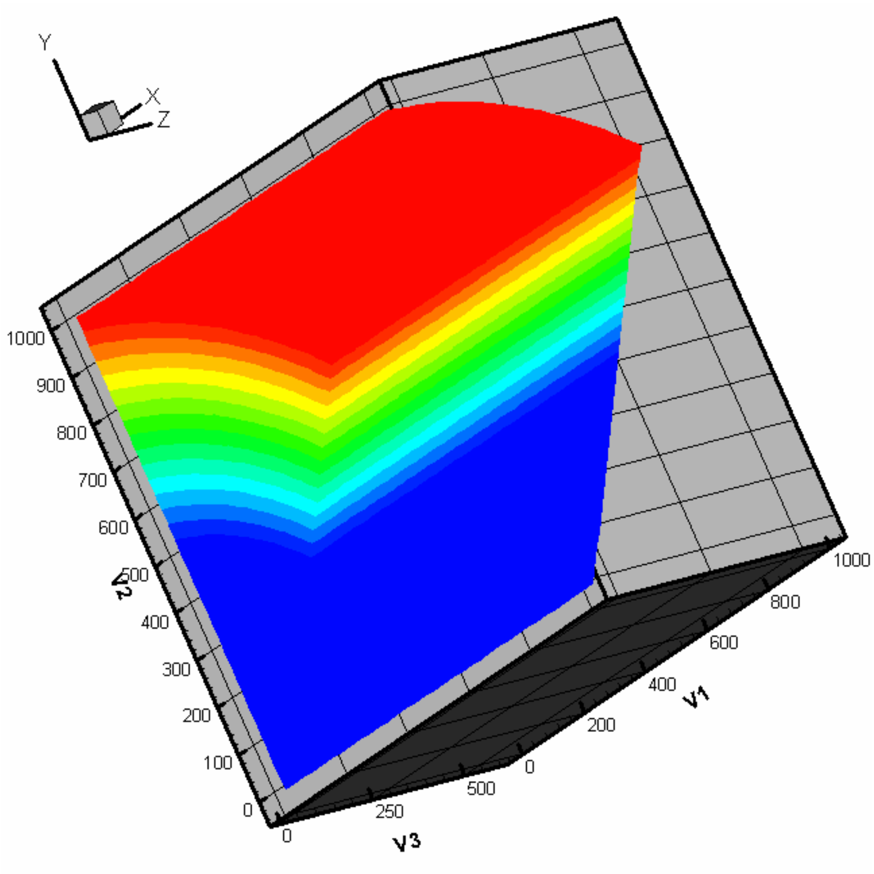
$$\|\nabla T(x)\| = \frac{1}{r_b(x)} \quad \text{in } \Omega, \quad r_b(x) > 0$$

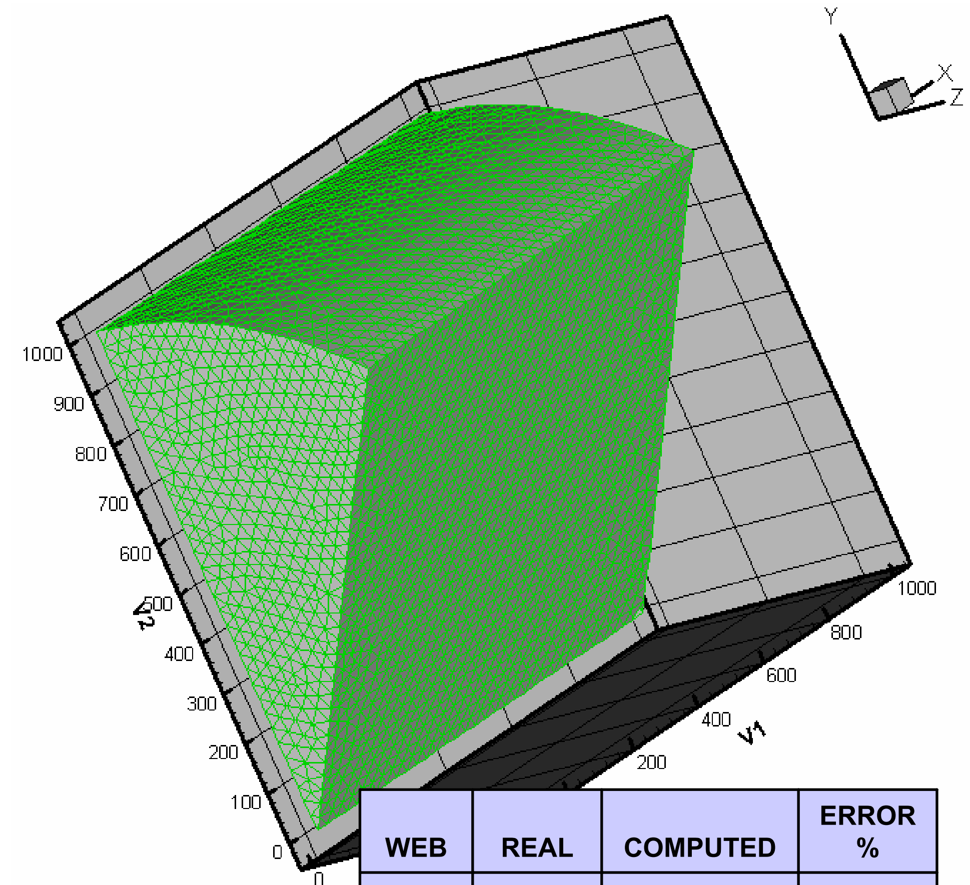
$$T = 0 \quad \text{on } \Gamma$$

Our Form of Equation

where r_b is the burn rate and T is the time of arrival of the burn surface.

Surface Regression

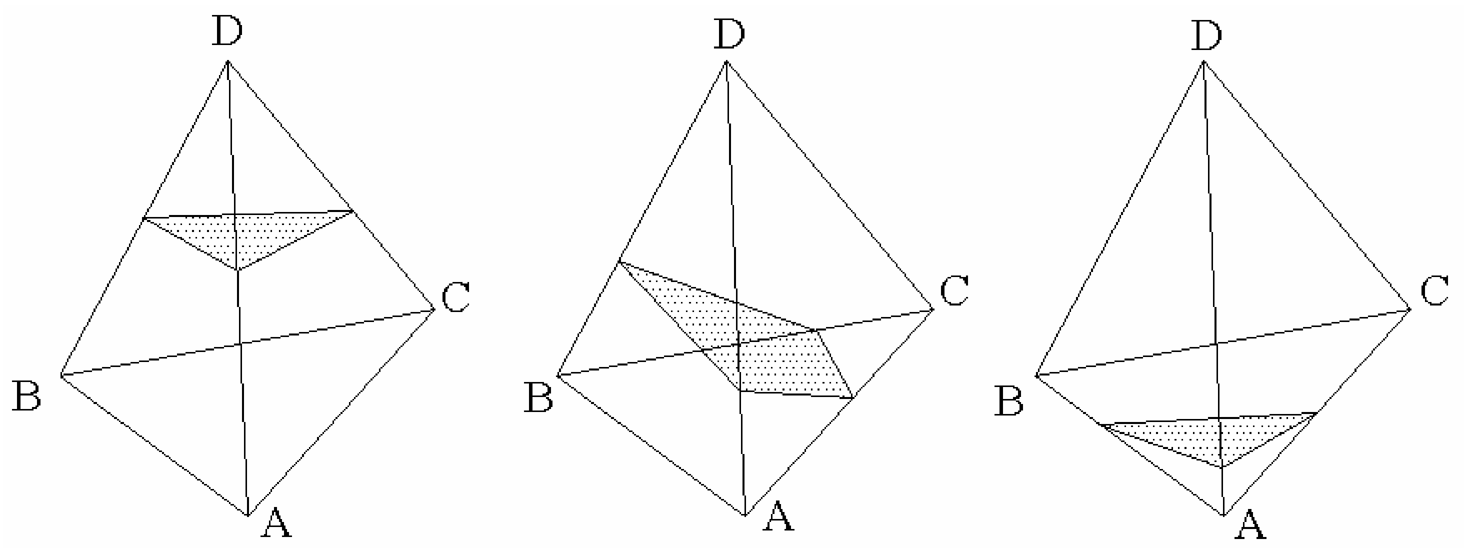




WEB	REAL	COMPUTED	ERROR %
100	376991	376959	0.00849
200	439822	439914	0.02092
300	502654	502795	0.02805
400	565486	565679	0.03413

Interface Capturing

1. T_0 is not inside the element.
2. $T_D > T_0 > T_C > T_B > T_A$ - The interface is a triangular element.
3. $T_D > T_C > T_0 > T_B > T_A$ - The interface is a quadrilateral element.
4. $T_D > T_C > T_B > T_0 > T_A$ - The interface is a triangular element.



(a) (b) (c)

Interface Capturing

There are **five** choices at this instant how this captured interface will be used.

1. Find the interface area vs web and supply this data to 0-dimensional solver.

2. Find the interface perimeter at stations along the motor vs web and supply this data to 1-dimensional solver.

3. Capture the 3-dimensional mesh and leave the interface elements as they are and supply this mesh to 3-dimensional hybrid solver.

4. Capture the 3-dimensional mesh and at the interface insert new tetrahedron elements and supply this mesh to 3-dimensional tetrahedron solver.

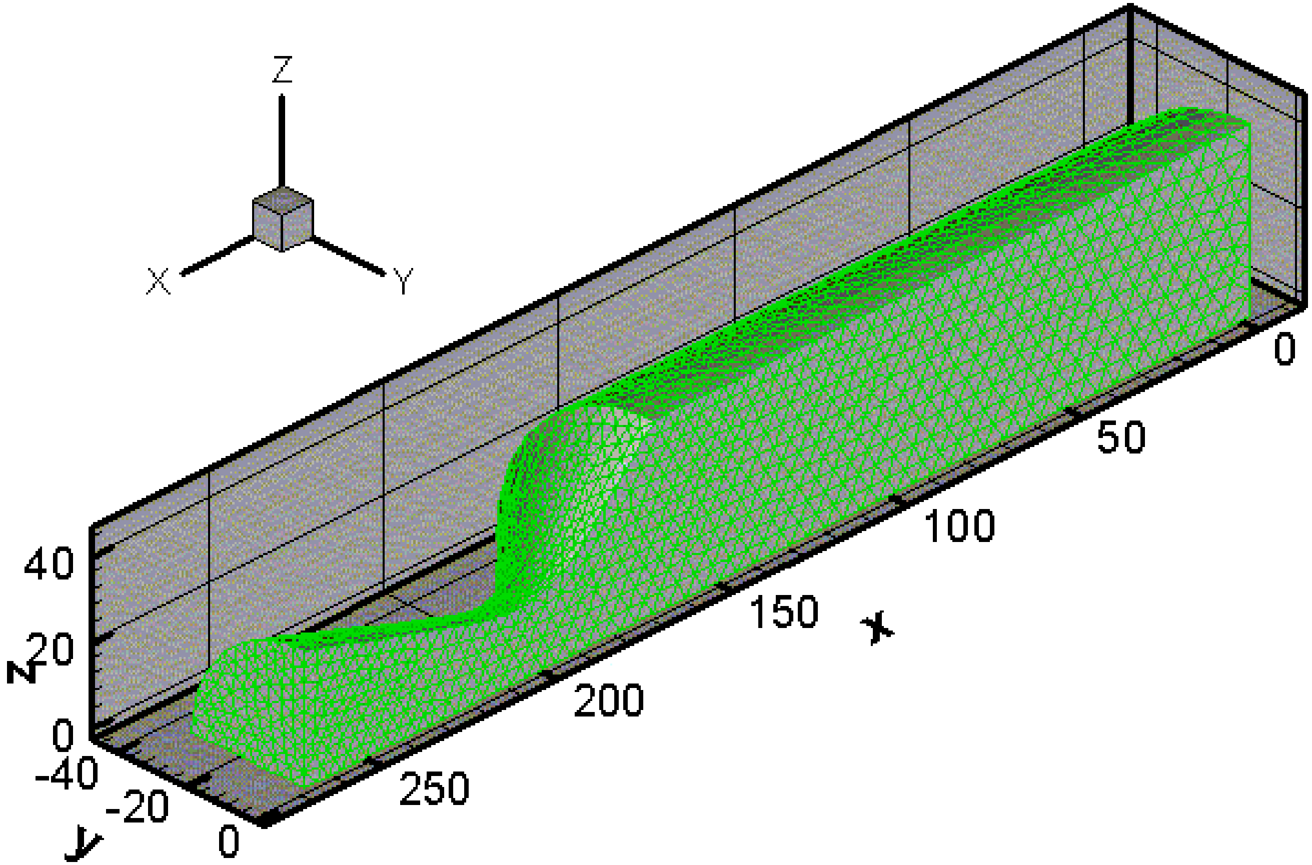
5. Capture the 3-dimensional mesh and at the interface move inner nodes to the boundary and supply this mesh to 3-dimensional tetrahedron solver.

Flow Solver

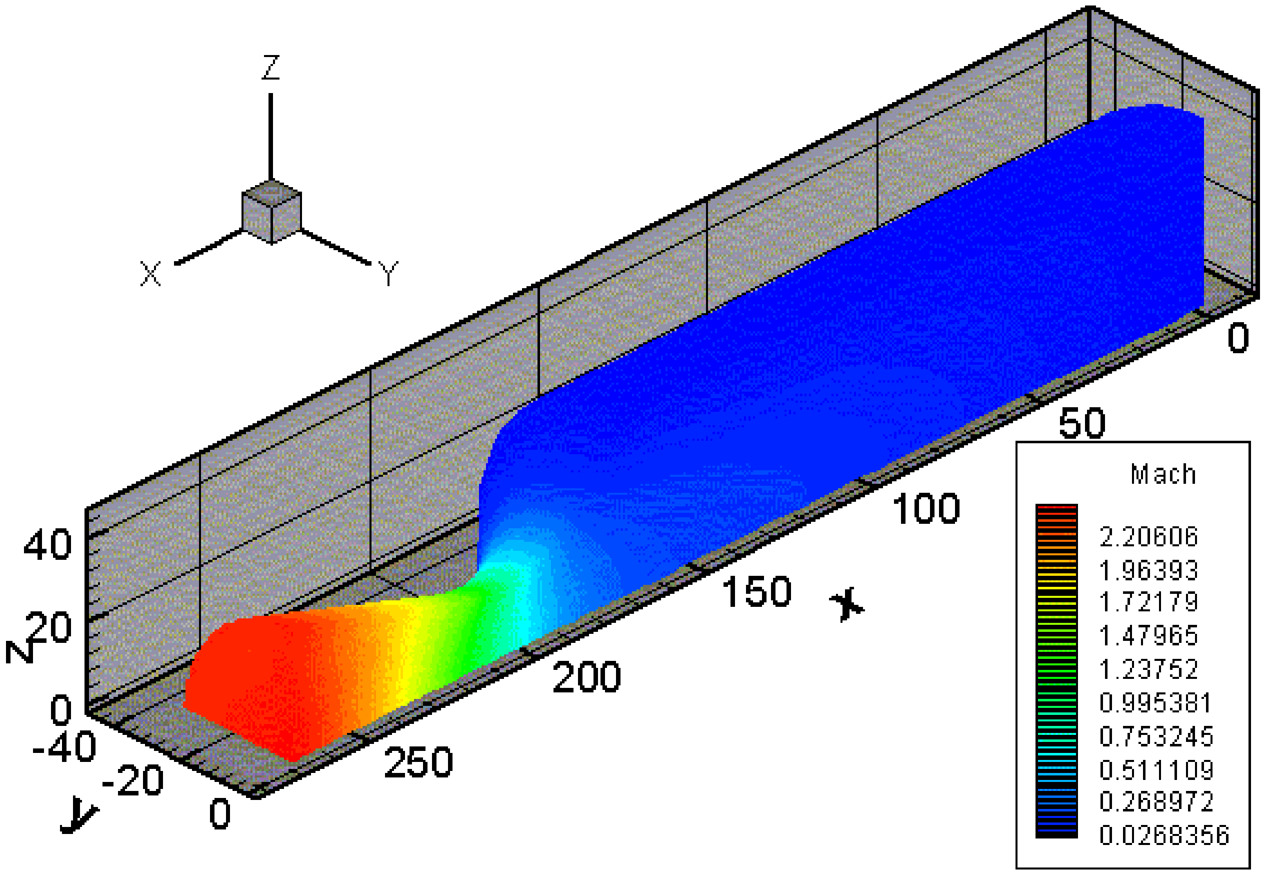
3-D FLOW SOLVER

- Euler, Internal, Finite Volume Solver
- Hybrid Mesh
- Explicit, RK4
- 2nd order accurate in space.
- Calculation of Flux: Upwind, SW, WL, Roe
- Boundary Conditions: Mass flux inlet, pressure exit, wall, symmetry

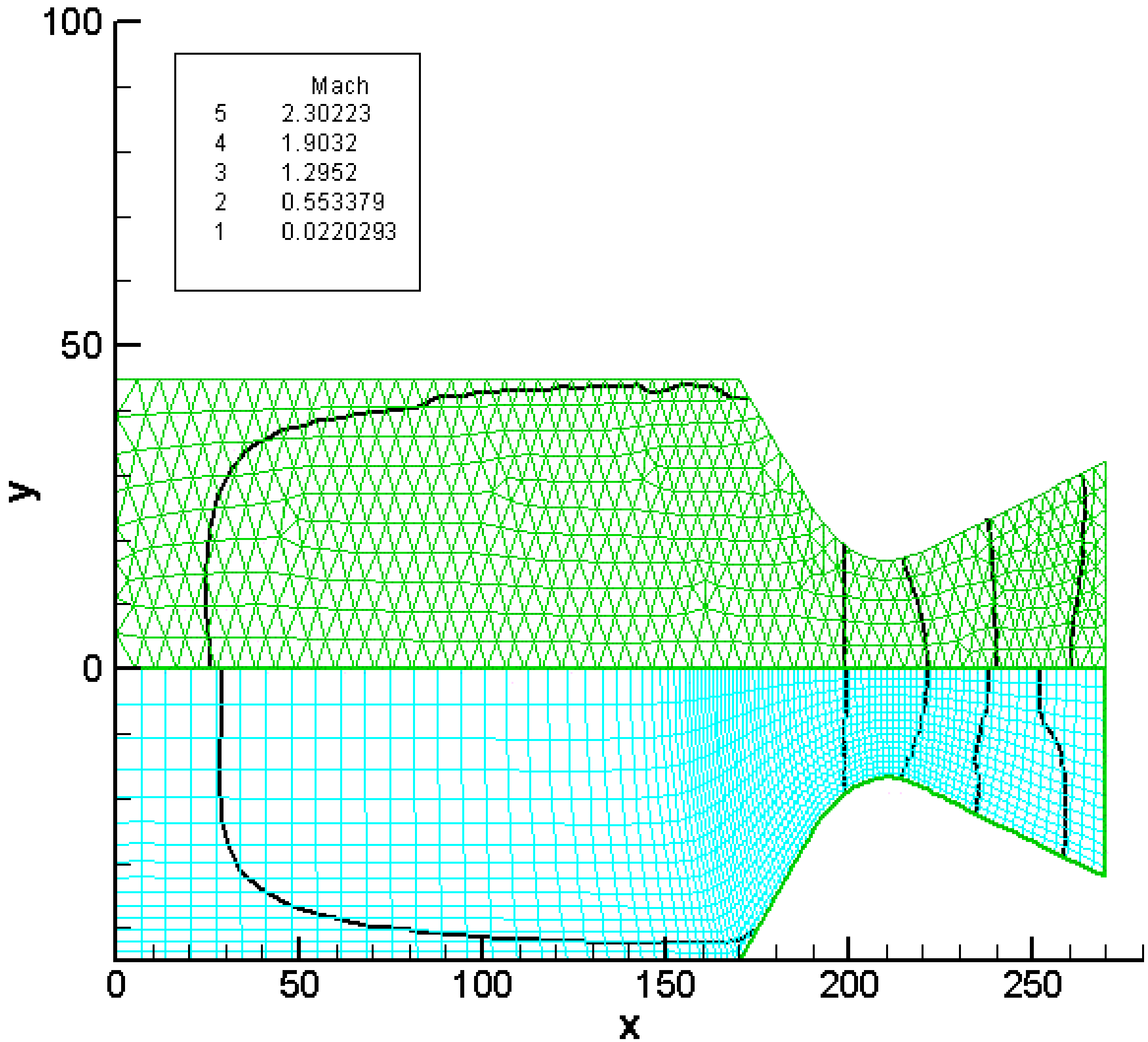
Flow Solver



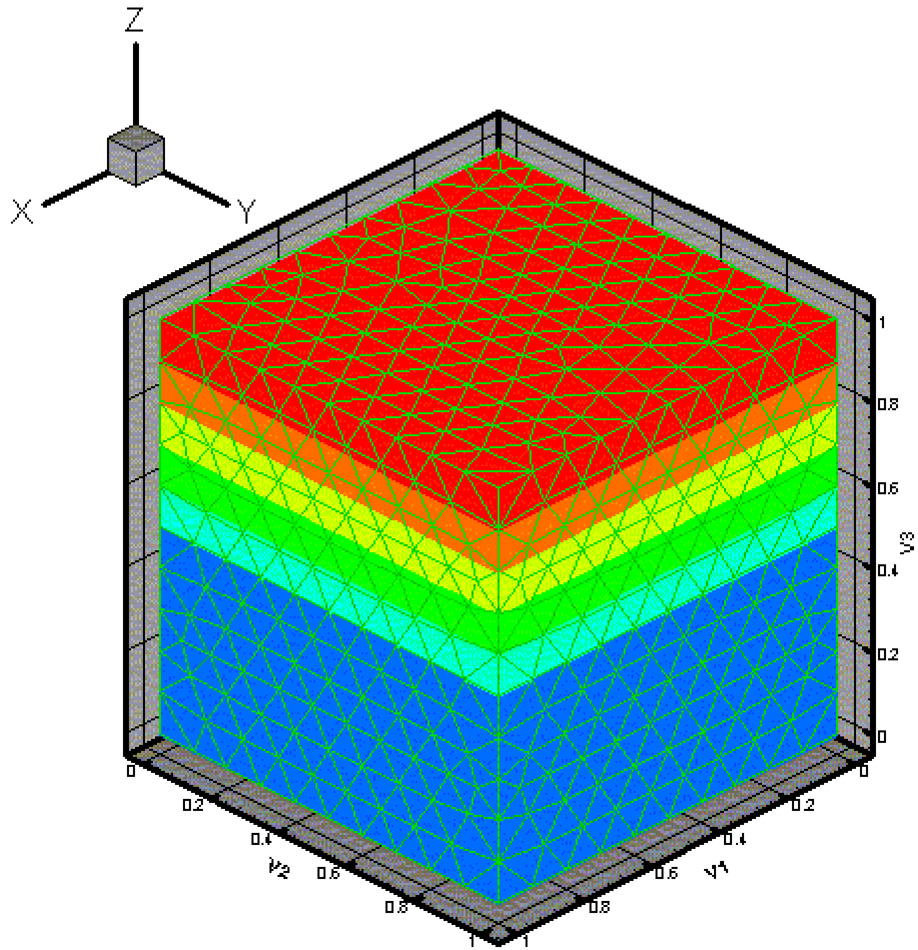
Flow Solver


Z
X
Y
40
20
Z
0
-40
-20
Y
0
250
200
150
X
100
50
0
Mach
2.20606
1.96393
1.72179
1.47965
1.23752
0.995381
0.753245
0.511109
0.268972
0.0268356

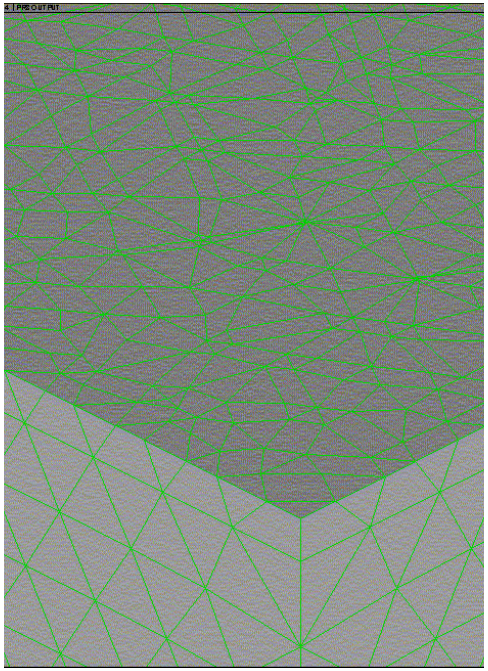
Flow Solver-3



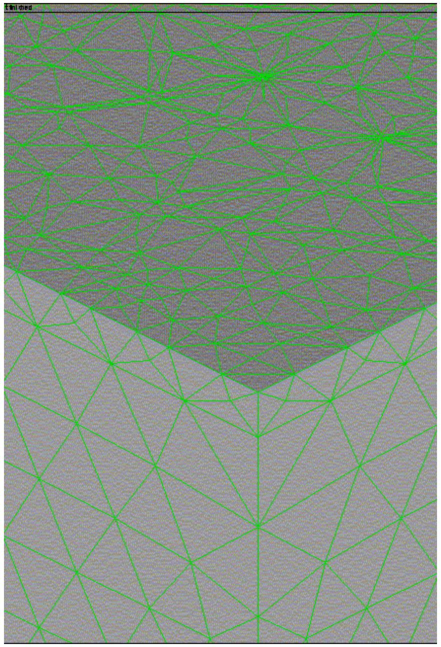
Test Case - 1



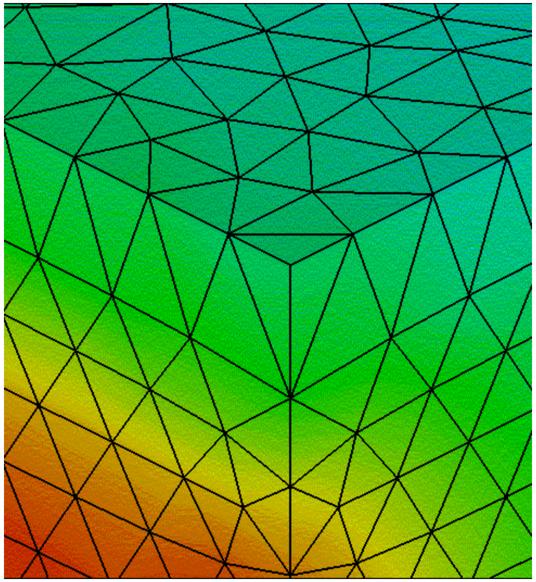
Test Case - 1



Hybrid Mesh



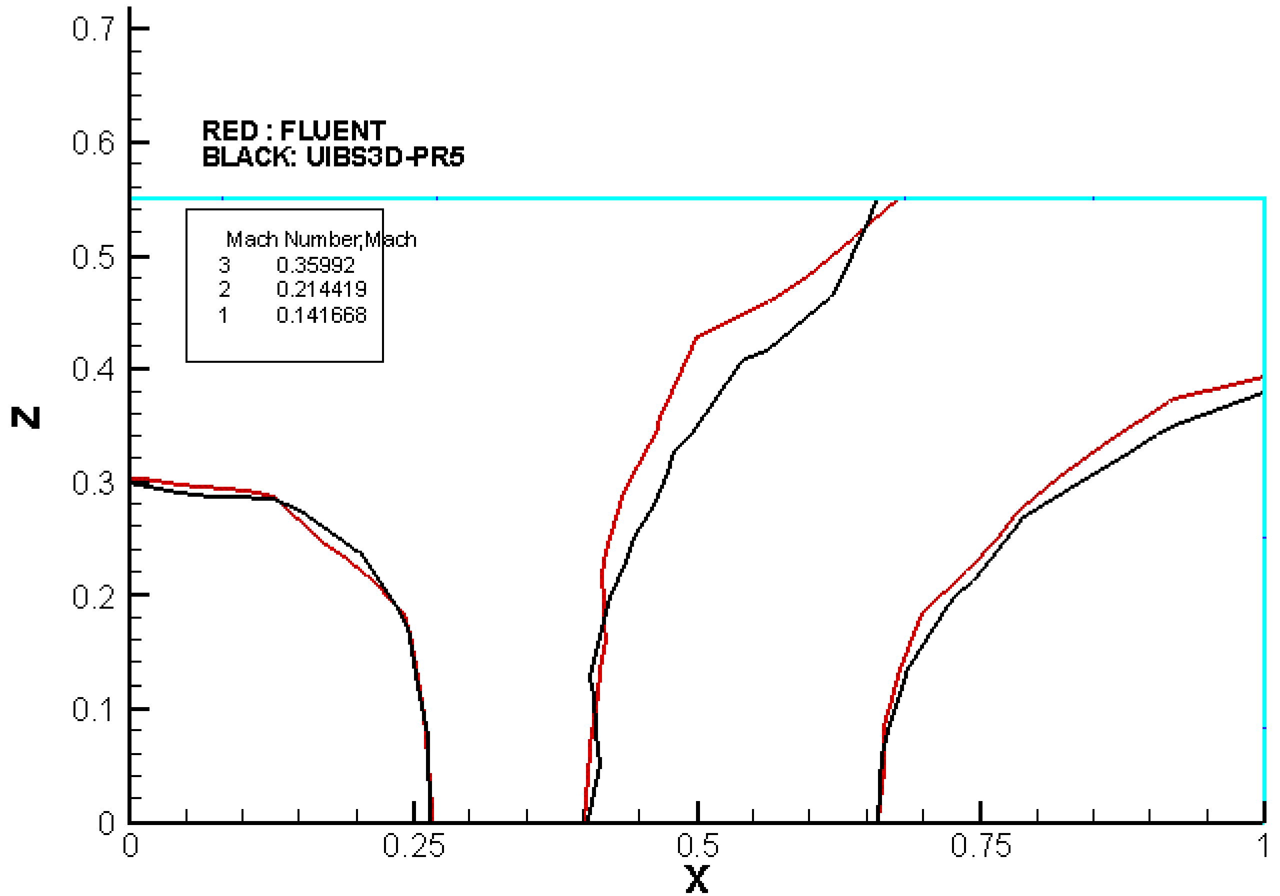
Sliced elements are converted into Tetrahedrons

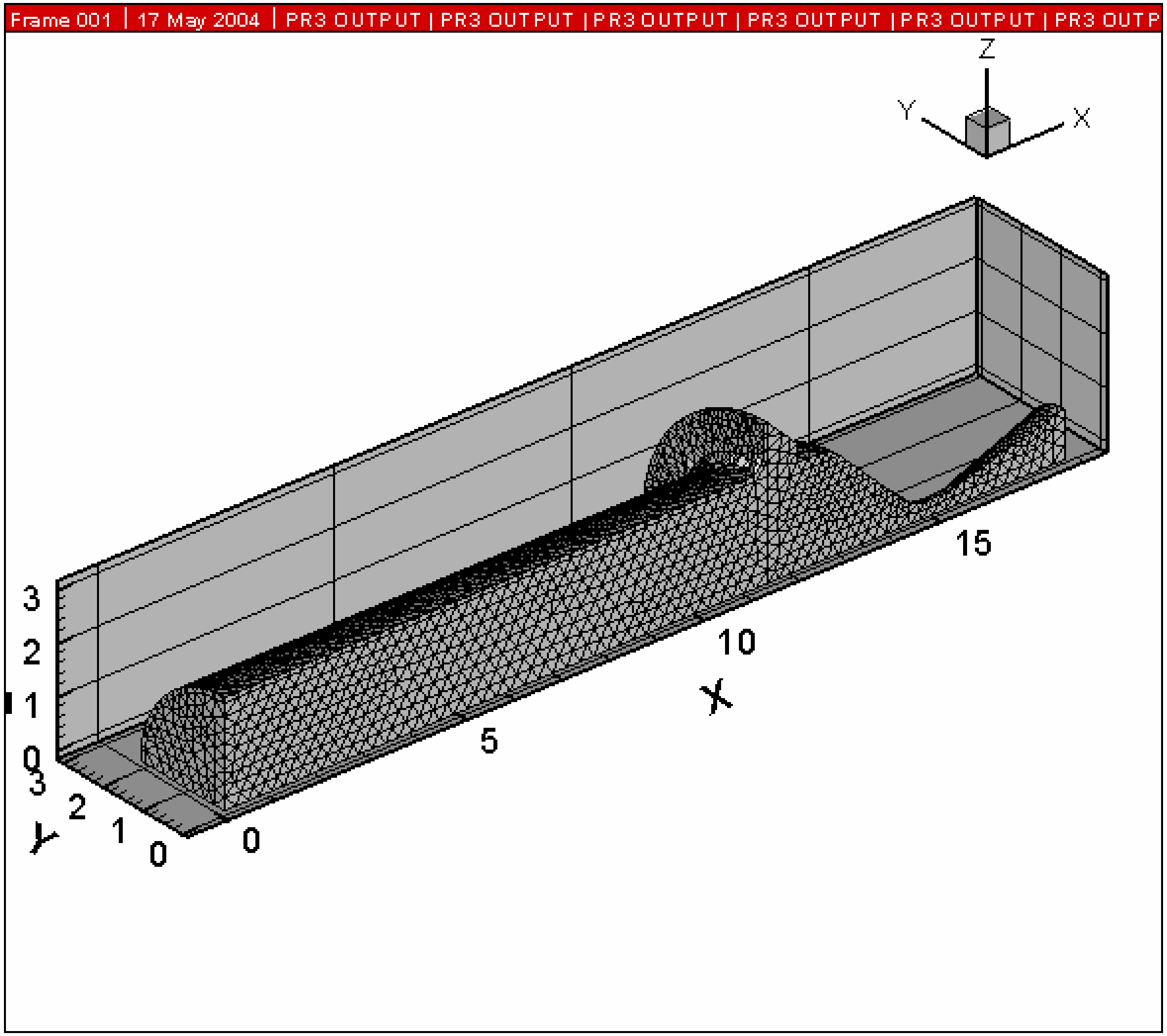


Moving inner nodes to interface

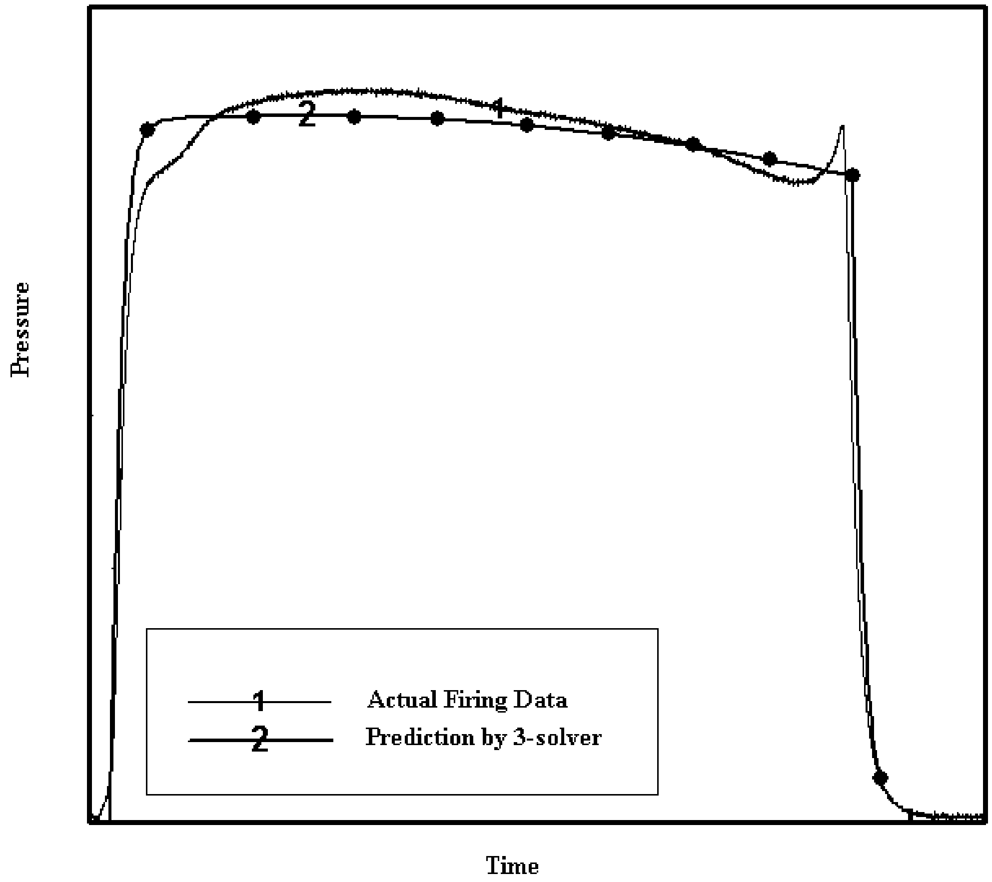
Test Case - 1

PR-5




Frame 001 | 17 May 2004 | PR3 OUTPUT | PR3 OUTPUT | PR3 OUTPUT | PR3 OUTPUT | PR3 OUTPUT | PR3 OUTP
Z
Y
X
3
2
1
0
3
2
1
0
Y
0
5
10
15
X

Test Case - 2



The results are obtained by constant propellant burn rate assuming inviscid ideal gas flow.